Lawrence Livermore National Laboratory

Program Update - April 2000

Laser Science & Technology

Dr. Howard T. Powell, Program Leader

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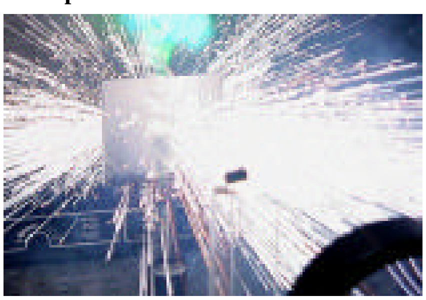
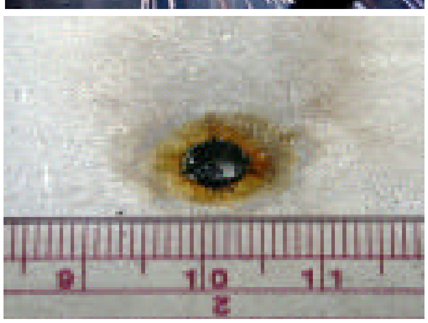
Modeling of Material Removal by the Heat-Capacity Laser

Under the support of Army Space and Missile Defense Command (SMDC), we are working with Raytheon to evaluate the effectiveness of pulsed solid-state lasers for target interaction, specifically material removal. Using the heat-capacity laser at LLNL, we performed a series of target interaction experiments. Coupons of steel, aluminum and carbon composite were irradiated by the laser beam. During these tests, the energy of the laser was kept at 80 J per pulse, with a pulse duration of 300- to 400-ms at a repetition rate of 10 Hz. Each laser pulse consisted of several relaxation-oscillation spikes with peak irradiance on target near 2 x 10^7 W/cm^2. The photos below shows some preliminary results made with the three-slab heat-capacity laser testbed. We were able to penetrate 2.3-mm plates of steel after about 13 laser pulses.





In order to optimize the pulse format for material removal and to guide future target interaction experiments, we are developing numerical models to simulate the material removal process. Using a one-dimensional vaporization-hydrodynamics model, we determined that vaporization was only part of the material removal rate observed in the experiments. A majority of the target material appears to be removed by liquid or solid ejection processes.

beam radius

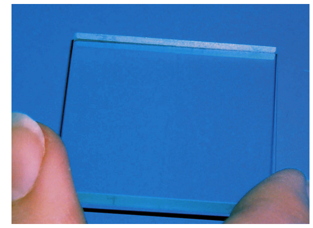
Calculated density distribution within the steel, after the pulse. The color scale gives the common logarithm of the density normalized by the solid density. The units are cm (vertically) and microns (horizontally), and the arrow gives the beam radius..

We employed a two-dimensional hydrodynamics code to model both ejection and vaporization. This code makes use of an Arbitrary Lagrangian-Eulerian mesh. It provides a unified description of phenomena within both the target and the blow-off region, which extends several centimeters from the surface. The photo above shows the progressive density depletion within the steel target during the irradiation pulse. Note the steep density gradient near the edge. Typical gas temperature near the target surface reaches 3000 to 4000 K and then cools to 2000 K at the end of the pulse.

We have also calculated the hole depth following the temporal profile of the irradiation pulse. After a threshold, the hole depth appears to increase proportionally with the laser energy absorbed. The final hole depth at the end of the pulse reaches about 175 μm, consistent with the hole depth achieved experimentally.

Further coupon experiments and detailed numerical modeling are planned. Simulation of the entire experiment requires a sequence of such calculations for each pulse, supplemented by thermal diffusion calculations during the interval between pulses. The continuous buildup of residual heat during successive pulses is anticipated to enhance the overall efficiency of material removal.

(C. Boley)



Yb:S-FAP Crystals Being Developed in a 4-x6-cm Size for the Mercury Laser

The Mercury laser is designed to be a 100-J, 10% efficient, 10-Hz laser operating at 1.047 nm. It is based on gas-cooled, diode-pumped crystal laser technology. When completed, it will be the highest energy pulse diode-pumped solid-state laser built to date. One of the critical elements in the Mercury laser development is the growth of high optical quality Yb:S-FAP [Yb^{3+}:$Sr_5(PO_4)_3F$] crystals for the large-aperture gain medium.

We have recently made several technical advances in the crystal growth areas. Yb:S-FAP crystals are grown by using the Czochralski method in which a boule is pulled from a molten mixture of the appropriate-composition starting materials. To minimize optical defects for high-power application, we precisely controlled the growth conditions. For example, an excess amount of SrF2 was added to the melt to remove the cloudiness commonly observed in crystals associated with incorrect stoichiometry. In addition, crystals were grown along a specific direction to eliminate anomalous optical absorption. Special procedures were also developed to “grow out” grain boundaries that cause unwanted waviness in crystals. Crystal-growth chambers with high thermal stability and controllable temperature gradient were developed to reduce voids (bubbles) in the crystal structure caused by unstable conditions at the crystal/melt interface. With the ability to successfully diffusion-bond Yb:S-FAP crystals together, smaller-diameter boules (2–3 cm) can now be bonded to yield high-optical-quality pieces for full size 4- x 6-cm slabs needed for Mercury. (K. Schaffers)

For comments about content of the *LS&T Program Update*, contact Dr. Hao-Lin Chen (925) 422-6198.
To get on the mailing list of the *LS&T Program Update*, send a request to Kim Baynes, baynes1@llnl.gov.
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